Off Site Manufacturing: Envisaging the Future Agenda

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1. Introduction

Off-Site Manufacturing (OSM) as a concept/approach is certainly not new, the origins of which rest in literature under various incarnations and typologies. Earliest examples include provision where "… a panelized wood house was shipped from England to Cape Ann in 1624 to provide housing for a shipping fleet" (Arieff, and Burkhart, 2003), through to the importation of housing in Australia (circa 1837), the delivery of Crystal Palace for "The Great Exhibition" in the United Kingdom (UK) (circa 1851), and for mainstream housing in the United States (US) with initiatives such as the Sears Modern Home "kit house" (circa 1908) and Lustron Home (circa 1945). However, there are several different terminologies in current use which describe OSM (Gibb and Pendlebury, 2006; Taylor, 2010); including: modern methods of construction, pod technology, off-site construction/fabrication/production, industrialised building systems, modular construction, pre-cast panels/foundations, volumetric/hybrid construction etc.

Whilst some would argue that OSM is still relatively and in its infancy, others would purport that OSM has now matured in a number of significant areas – evidenced through several innovative companies in the US, UK, Japan, Sweden, Malaysia, Germany, and Poland (to name but a few); and that these are now starting to transform the industry. That being said, OSM has a relatively low percentage of the market. This is rather complex to understand and unpick due to a myriad of factors, not least: historical perception, entrenched positioning and traditionalist thinking, lack of supply chain integration, limited availability of bespoke manufacturing plants, skills shortages, and [perhaps more importantly] lack of evidenced-based OSM business models. Given these, one might expect 'risk' to rest high on the agenda of companies – especially when 'tried and tested' approaches tend to rest more comfortably with decision-makers. These issues therefore present some significant challenges for OSM stakeholders. Conversely, several companies have now abandoned the "wait and see" approach often typified with innovation adoption [*cf.* leaders/laggards and innovation decisions] (Rogers, 2003). These companies have started to pioneer new products and services that transcend traditional OSM approaches; and in doing so, have embedded new social, cultural, political and economic drivers into meaningful determinative business constructs with clear evidential chains.

This chapter presents a personal and somewhat reflective narrative on the core pivotal issues that have seemingly affected OSM uptake and dissemination. It explains these interconnected constructs using primary and secondary data to triangulate macro, meso and micro drivers, which it is proffered, are linchpin levers for success (or failure). This work builds on previously published empirical evidence and new research especially commission for this chapter in order to secure relevance, generalisability and overall fidelity. This culminates in the presentation of a new OSM future agenda model, supported by three learning points for wider reflection.

2. Literature: Historical Refection and Future Gazing

2.1 *Introduction*

Definitions aside, this chapter assumes the position that prefabrication and modular construction falls under one offsite construction 'umbrella'. In doing so, the term "OSM" is used as a collective term which encapsulates this position in order to remove delineator ambiguity.

Whilst the origins and derivations of OSM are clearly espoused in extant literature, empirical evidence from Architecture, Engineering and Construction (AEC) highlights a number of topics that still need to be explored in order to address historical [entrenched] challenges – from fragmentation, through to procurement, perception, 'value for money', 'sustainability', stakeholder integration etc. This list is seemingly endless. However, what is important is not so much "…what has happened…and…what have we done…", but what have we learned? At face value, this comment in itself may be perceived to be rather simplistic and naïve; it is not meant to be, it is used to segue discussion, noting that contextual reflection is needed before any future gazing can begin.

The off-site market is still relatively small in comparison with traditional design/engineering/construction approaches. The reasons for this are multi-layered and complex. Whilst some countries have embraced OSM more than others, there are a number of sentient concomitant factors which either directly or indirectly influence market acceptance. The underlying issues are predominantly historical and somewhat context (country) specific. These can loosely be coupled into six core areas, these being: i) lack of awareness; ii) supply chain challenges (capacity and knowledge); iii) cultural perception; iv) organisational and market maturity; v) lack of viable business process models/solutions; and vi) a significant perceived skill gap (design/manufacturing/construction). Thus, in order to understand some of these challenges it is important to dissect these six areas into meaningful 'push-pull' forces. The following sections explain some of these issues by discussing: OSM precepts (and context; the interrelationship of design, construction and manufacturing to 'people', 'process' and 'technology'; the impact of innovation and change on OSM; and the need to disentangle OSM business models and strategy with clearer evidential chains supported by transparent signposting criteria.

2.2 *OSM: Precepts and Context*

The underlying precepts of OSM predominantly rest with moving construction-related activities (traditionally performed on site) into a controlled environment - typically a manufacturing or factory facility (Arif and Egbu, 2010; Gibb and Isack, 2010; Blismas and Wakefield, 2009). In this respect, offsite construction has been espoused as offering several benefits over 'traditional' construction approaches, including: higher speed of delivery, improved quality of the finished product, lower costs and lower on-site labour requirements (KPMG, 2016; Nadim and Goulding, 2011; Li *et al*., 2011; MBI, 2010). Acknowledging these opportunities, several influential bodies called for AEC to revisit OSM in order to address the recurrent industry challenges highlighted earlier. In the UK alone, selective examples include: "Constructing the Team. Final Report of the Government/Industry Review of Procurement and Contractual Arrangements in the UK Construction Industry" (Latham, 1994); "Rethinking Construction" (Egan, 1998); "Never waste a good crisis: a review of progress since Rethinking

Construction and thoughts for our future" (Wolstenholme, 2009); and "The Farmer Review of the UK Construction Labour Model: Modernise or Die" (Farmer, 2016).

Whilst these studies have advocated the need to promote OSM, uptake has been lower than anticipated, accounting for approximately 7% in the UK (KPMG, 2016) – but with strong market growth potential (AMA Research, 2018). Given that OSM uptake is still relatively low, it is important to understand why this is still the case, as correlation between countries seems to be anchored in socio-economic and political contexts. For example, some studies have identified that industry reluctance to embrace off-site was "…largely attributable (amongst others) to the unsuccessful past experiences associated with this approach." (Nadim and Goulding, 2011). Others have identified issues such as: policy and regulations, lack of knowledge/expertise, low levels of standardisation, and the presence of dominated traditional project processes – which still dominate the market (Gan *et al.*, 2018). Moreover, even though the UK has a strong heritage in OSM, it seems that the barriers to the wider uptake of OSM are still unfolding (Parliament 2018).

It is therefore apparent that context is a significant driver of OSM. This not only influences adoption and uptake, but also the general perception of OSM (from a demand perspective). For example, the North American market is completely different to Europe, which is again different to the Asia-Pacific region. Nuances, context and market maturity aside, globally, the compound annual growth rate for the modular market is still expected to grow by 5.95%, with key players identified as being "…ACS Group (Spain), Skanska AB (Sweden), Komatsu Ltd (Japan), L&T (India), Balfour Beatty Plc. (U.K.), Kiewit Corporation (U.S.), Taisei Corporation (Japan), Red Sea Housing Services (Saudi Arabia), System House R & C Co. Ltd (Japan), Bouygues Construction (France) and others" (ReportBuyer, 2017). Given this predicted growth, it is important to uncover the significant patterns originating from this data, particularly to understand how AEC can [more] purposefully leverage OSM strategies.

2.3 *Innovation and Change*

Innovation has often been defined in various ways and through different disciplines, lens and foci. The underlying concept of innovation however, often involves changing or doing something different from 'mainstream' competitors. The central tenet and rationale for pursuing innovation is ostensibly driven by a number of factors, not least, organisational excellence [brand distinction], efficiency gains, product differentiation, or unique ways of creating strategic advantage [to make money]. A number of studies have investigated the benefits of innovation on business performance, production, and economic growth (Schumpeter, 1934; Kanter, 1983; Drucker, 2007). The innovation 'umbrella' includes several derivations, from the creation of new ideas or solutions, through to product/process efficiencies, technologies and business strategies/models. Therefore, organisations that innovate tend to embrace change more frequently (in order to leverage this innovation) than those that do not [*n.b.* innovation should not be confused with exnovation].

Within AEC literature, the scope and measurement of Construction Innovation (CI) is somewhat difficult to distinguish as "…measurement is difficult and so may not always be reliable, or safely contrasted with other sectors. This is because inter-alia of the scope of CI activities and numerous delineations." (Holt and Goulding, 2016). On this theme, Winch (2003) noted that discrepancies in classifications did not naturally lend itself to make like-for-like comparisons. However, at this juncture it is also important to note that AEC can also learn a lot from other sectors, especially in comparison with the world's most innovative companies (*cf.* Forbes, 2018). That being said, a number of AEC exemplars have been discussed and critiqued in extant literature, including: models of construction innovation (Slaughter, 1998); small firms (Sexton and Barrett, 2003); innovation champions (Dulaimi *et al.*, 2005) firm complexity/coupling (Dubois and Gadde, 2002), and business strategy (Seaden *et al.*, 2003).

Acknowledging the importance of innovation (especially relating to OSM), it is proffered that there is an explicit need to appreciate the dynamics and interconnections that nurture (or stifle) innovation. This is so important, as understanding these issues can help focus energies on such matters as: OSM business strategy, process, design, market capacity/absorption, risk and return on investment (to name but a few). On this subject, there are a number of AEC showcase exemplars that can be used to provide the appropriate evidence needed to support the OSM market. Finally, it is important to note that AEC does in fact innovate and the "…construction industry clearly has a lot to be proud of and it is important to recognise this." (Loosemore, 2014).

2.4 *OSM Business Strategy: Evidential Chains and Signposting*

Within a commercial context, business strategy (sometimes referred to as corporate strategy) is the pattern of corporate decisions taken which then determine organisational goals and objectives. The precise definition and scope of business strategy varies by perceptions and methodological approaches (Ansof, 1970; Porter, 1985; Mintzberg and Quinn, 1991; Robson, 1997; Peppard and Ward, 2016). However, rubrics, definitions and etymology aside, consensus of business strategy typically involves the establishment of policies and plans to achieve strategy or strategic direction - where for example, Porter (1979; 1985) was acknowledged as being one of the pioneers of strategic decision-making in competitive environments. Business strategy typically embraces all collective actions that govern business functions – from intellectual capital (people engaged in the company), through to: management and leadership style, organisational structure, and socio-political, economic, technical and cultural issues (including the consideration of shareholders in some instances). Intrinsically, the business strategy focuses on how a company competes and positions itself in the marketplace; in particular, how it focuses resources to convert competence, product and *esprit de corps* into a viable business proposition which ultimately [hopefully] delivers strategic advantage. Given this, the range and variety of strategies available for implementation is almost infinite, from return on equity/capital employed, through to market dominance or continued growth. The driving force of these strategies is normally focussed through a 'mission statement', 'company vision' or 'statement of intent'. These terms are often used interchangeably (Robson, 1997), but are principally all designed to articulate corporate goals and objectives.

One of the inhibitors/barriers to OSM adoption is a general lack of detailed understanding on the actual 'mechanics' and 'typical' content needed to support and deliver a typical OSM business strategy. Issues raised tend to include: market demand, competition, product development, marketing, start-up capital requirements (plant/machinery, factories etc.), resources (pre/post adoption), and process delivery schedules cognisant of Design for Manufacture and Assembly (DfMA), skills and training, general logistics and supply chain integration, procurement options and legal compliance/warranty requirements, payback (return on investment) etc. These issues alone require considerable thought, as these help populate the data needed for decision-making and the evidential chains (indicators) needed to underpin or justify decisions. For example, Blismas *et al.,* (2006) observed that evaluation needed to be more holistic and value-based rather than cost-based, and that this was affecting the uptake of off-site. Moreover, it was also acknowledged that there was an intrinsic need to understand business systems and international production systems (within the contextual operating environment); including the detailed characteristics of these, and how they related to business and *systems theory* (Martin, 2013). This also resonates with other issues, including *organisational theory* (intellectual capital structured to deliver organisational goals), *contingency theory* (contingent actions aligned to internal/external environment), and the wider constructs of management, economics, marketing, innovation etc. Some attempts in AEC literature have been made to provide further clarity on these issues, including: Jonsson and Rudberg (2014), who used *production strategy theory* to develop a matrix which linked market requirements with the product offering and the design of the production system. Similarly, (Sutrisna *et al.*, 2018) developed a work breakdown matrix for manufacturing deliverables/activities in order to more effectively manage offsite construction projects; and Pan and Sidwell, (2011), who proffered that there was a need to understand or demystify the cost barriers associated with OSM – noting that approaches as "…efficiency learning, technological innovation, multinational partnering, and 'in-house' build management." could be used to "…encourage offsite construction in the future."

3. Research Methodology

3.1 *Underpinning Research, Context and Positioning*

This chapter brings together a number of OSM initiatives, including formative findings from literature, research and development, and practice-based evidence from OSM projects. From a research context perspective, the starting point of the work presented here develops findings from a research roadmap produced through a CIB Task Group TG74 New Production and Business Models in Construction (Goulding and Arif, 2013). Findings highlighted a series of interconnected issues in nine core areas, covering three main drivers of OSM [people, process, and technology] and their impact on AEC [Design, Manufacturing and Construction] – see Figure 1.

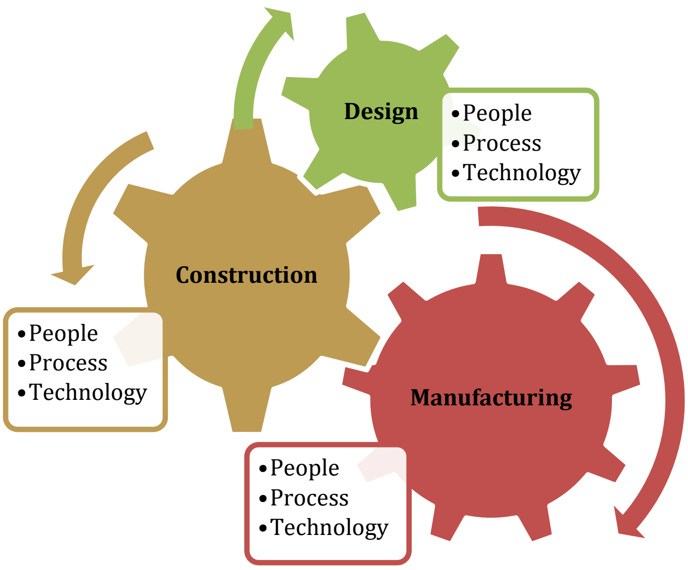

Figure 1: Core Interrelated Issues from CIB Roadmap (Goulding and Arif, 2013)

From Figure 1, it was acknowledged that further work was needed to understand the challenges and opportunities that OSM presented. From this, a model was prepared through the CIB TG74 Task Group to depict what was needed for the future OSM agenda (Figure 2).

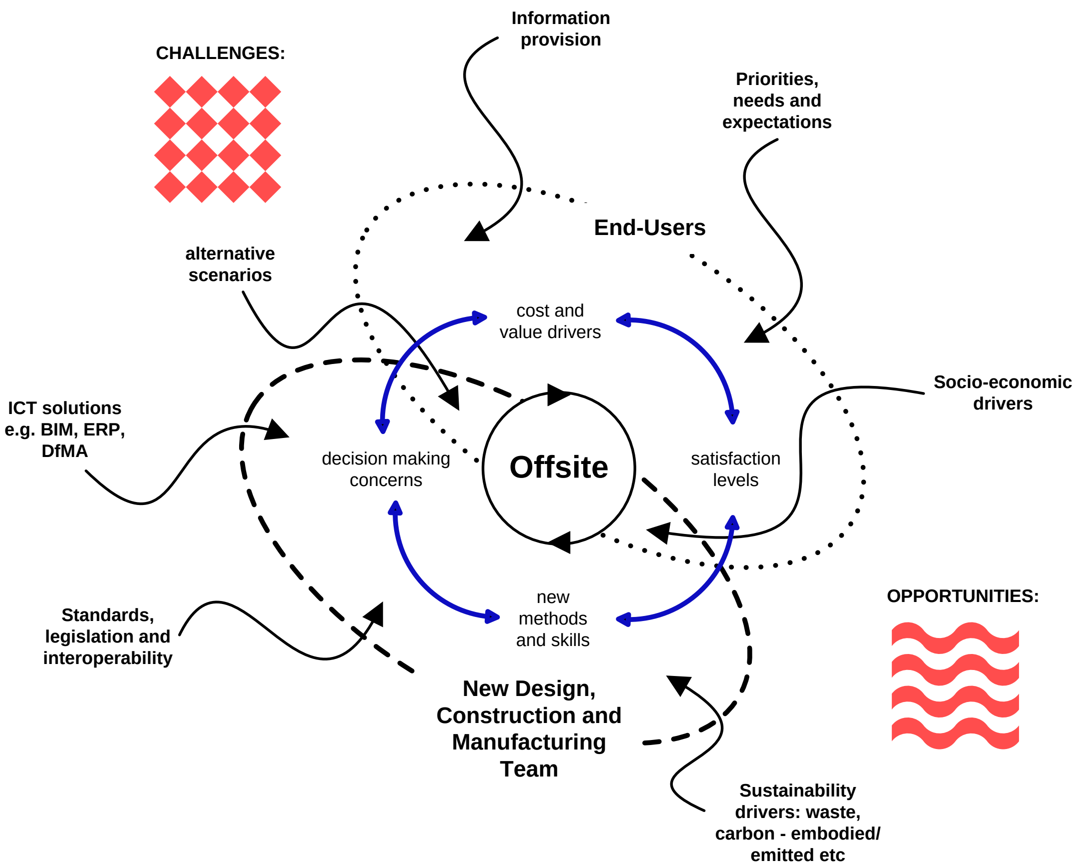

Figure 2: Future Research Agenda for Offsite (Goulding and Arif, 2013)

In order to provide readers with additional context for subsequent sections of this chapter, the following narrative explains some of the findings from this research.

<u>Design-Technology</u>

It is important to reflect on the manufacturing sector from a manufacturing perspective in order to appreciate the rich context, rationale and subsequent learning opportunities this affords. This includes such issues as: customer focus and implementation of Design for Variety (DFV) principles (Veenstra *et al.*, 2006); or engaging product design optimisation techniques with evaluative criteria (Yoshimura, 2008). This requires embedding technology into the early design process, including emerging technologies standards such as Building Information Modelling (BIM) relating to OSM (Nawari, 2012). Major Design-Technology issues included the need for: 1) enhanced design processes; 2) greater BIM adoption; and 3) clearer supply chain benefits.

Manufacturing-Technology

A key debate in manufacturing technology is the actual level of automation required (Frohm *et al.*, 2008; Skibniewski, 1992). This naturally includes justifying automation in construction with a high product variety and significant demand variations (Veenstra *et al.*, 2006; Wikberg *et al.*, 2010); which requires flexible and reconfigurable manufacturing systems (Colombo and Harrison, 2008); effective and cohesive supply chains (Arif *et al.*, 2005), and the integration of modelling, simulation and decision support systems (Fruchter, 1998). Major Manufacturing-Technology issues included the need for: 1) advanced simulation and modelling; 2) business cases for new software development; and 3) optimisation of the manufacturing payback period.

Construction-Technology

Construction processes are highly dependent on planning processes and logistics associated with the delivery process. Advanced design/planning tools and data-rich models are vital in this respect (Eastman *et al*., 1974; Fischer and Kunz, 2004) to facilitate and enable design coordination and subsequent fabrication. This is very important for OSM as it provides a number of clear indicators (Nawari, 2012). The construction-technology debate also acknowledged new types of construction technologies that were more conducive to assembly than traditional construction *per se*. Major Construction-Technology issues included the need to: 1) identify technology support tools; 2) better understand risk analysis; and 3) improve product modelling flow.

Design-Process

This acknowledged that the implementation of manufacturing in the design-process (including design management) needed to be more systematic (Fruchter and Demian, 2002; Whitney, 1990). This required critical reflection on value-added activities – from: design decisions, analysis of impact on stakeholders, through to an improved understanding of the overall impact of design on the manufacturing and construction processes. Major Design-Process issues included the need to: 1) add value to the process; 2) improve the impact of design/technology; 3) undertake better lifecycle process analysis.

Manufacturing-Process

This involved dealing with the manufacturing of construction products, including the need for a higher degree of customer involvement (Stump and Badurdeen, 2012), which by default required the evaluation of alternate business models in order to secure effective solutions. Major Manufacturing-Process issues included the need to: 1) learn from other industries; 2) develop new business models; 3) identify the break-even point for automation.

Construction-Process

This highlighted the importance of construction processes, and the relationship to offsite construction and business models (Pan and Goodier, 2012). This incorporated the need to reflect on the top-down or bottom-up strategy for developing robust business and operating models. These also needed to clearly identify the relationship between construction and the actual processes involved. Major Construction-Process issues included the need to: 1) integrate process with BIM; 2) leverage production flexibility; and 3) improve the interface of off-site production.

Manufacturing-People

Manufacturing projects typically differ from traditional construction schemes as they are predominantly more product-focused rather than project-focused (Kagioglou *et al.*, 2000). In order for manufacturing to deliver more effective construction products, it was important that a project-centric view (of the product) needed to be adopted. This requires close collaboration through both design and implementation. Major Manufacturing-People issues included the need to: 1) integrate decision modelling; 2) maximise the impact of training; and 3) align new job roles to support delivery.

Design-People

This highlighted the need to inform people on the different types of manufacturing-oriented design approaches that can be adopted, including DfMA and concurrent engineering. This was considered vital for reducing production costs, cognisant that design conflicts often lead to rework during the manufacturing process (Li *et al*., 2011). Major Design-People issues included the need to: 1) embrace manufacturing-oriented design approaches); 2) adopt new approaches for conventional design approaches; and 3) develop new skills to meet this demand.

Construction-People

This category recognised that the adoption or migration to OSM would typically require people to be retrained with assembly-type skills, rather than conventional construction skills. This up-skilling should also embrace new paradigms of construction (Egan, 1998) including lean construction (Nahmens and Ikuma, 2012). Major Construction-People issues included the need to: 1) promote sustainability; 2) up-skill existing personnel 3) improve Health and Safety processes.

3.2 *Research Findings Informing the Methodological Approach*

To support the above findings, additional research was undertaken on the nine core areas presented in Figure 1 and issues embedded in the "Future Research Agenda for Offsite" (Figure 2). This additional research engaged a team of 18 OSM 'experts' from manufacturing, construction and design, including representatives from research institutions and consultancy bodies. The approach adopted used two blind parallel workshop settings to critique the issues highlighted in Figure 2. Respondents were divided into two groups of nine, with an equal distribution of expertise deemed representative to make informed decisions. These groups were also supported by a discussion moderator. These workshops were divided into four sessions, namely: introduction, individual survey, within-group discussions, and between-groups discussion. Participants were provided with an overview of the nine objectives of the study and rationale behind each of the 27 sections. Likert Scale questions were used for gauging the 'importance' of each issue (along with its corresponding timeframe: 0-5 years, 6-10 years, and 11-15 years). In addition, an 'importance' field offered respondents three options (Low, Medium, High) on the importance of each issue. Within-group discussions were also used to secure consensus. Discussions from these two sessions were then transcribed and coded for qualitative data analysis and triangulation purposes.

From a data analysis perspective, statistical data from the survey was coded and stored as an SPSS data file. SPSS version 17.0 was used to facilitate the descriptive and inferential statistical analysis. Inferential Analysis of Variance (ANOVA) Methods were employed to examine the differences between both dependent and independent variables, cognisant of statistical model assumptions (normality, homogeneity, and independence). Tukey's Honestly Significant Difference test was selected as the Post Hoc test for accurately maintaining alpha levels at their intended values (Zagumny, 2001). This study conducted both in-between and within-groups analysis for all nine areas (People, Process, Technology mapped against Design, Manufacturing and Construction). These findings are reported in detail (Goulding *et al.*, 2015), a synopsis of which is presented in Table 1.

Table 1: ANOVA Test Results: Timeframe and Process (Goulding et al., 2015)

Dependent Variable	Design-Process N1= 13, N2=11, N3=11				Construction-Process N1= 14, N2=11, N3= 13				Manufacturing-Process N1=12, N2= 12, N3= 11			
(I) Development Area	Mean Std. Dev.	(J) Area	Mean Diff. (J-I)	Sig.	Mean Std. Dev.	(J) Area	Mean Diff. (J-I)	Sig.	Mean Std. Dev.	(J) Area	Mean Diff. (J-I)	Sig.
Var1	1.23	Var2	-0.68*	0.04	1.29	Var2	-0.17	0.71	1.33	Var2	-0.33	0.51
	0.60	Var3	-0.04	0.99	0.47	Var3	0.05	0.96	0.65	Var3	-0.48	0.26
Var2	1.91	Var1	0.68*	0.04	1.45	Var1	0.17	0.71	1.67	Var1	0.33	0.51
	0.70	Var3	0.64	0.07	0.69	Var3	0.22	0.56	0.78	Var3	-0.15	0.87
Var3	1.27	Var1	0.04	0.99	1.23	Var1	-0.05	0.96	1.82	Var1	0.48	0.26
	0.65	Var2	-0.64	0.07	0.44	Var2	-0.22	0.56	0.75	Var2	0.15	0.87
Total	1.46	Among	f=3.93	0.03	1.32	Among	f=0.56	0.57	1.60	Among	f=1.35	0.27
	0.70	groups	df =34		0.53	groups	df=37		0.74	groups	df=34	

**p<.05 (Significant Difference), **p<.01 (Very Significant Difference), ***p<.001 (Absolutely Significant Difference); 1<Mean<1.5 (Short-term Changes); 1.5<Mean<2 (Medium term Changes); 2<Mean<3 (Long-term Changes)*

Table 1 presents significant difference of opinions among respondents' timeframe (f=3.93, df=34, and p<.05). Findings highlighted an urgent need to i) define added value to the business processes (Var1); ii) to engage lifecycle process analysis and stakeholder analysis (Var2); and iii) to understand the impact of design and process on business and technology (Var3). In terms of Construction-Process, it was noted that processes in manufactured construction could be re-augmented to replicate the assembly process; but there needed to be a complete re-think of the construction philosophy. This included mind-set change and re-training - to enable staff to think differently in order to synchronise processes and activities with manufacturing and design (from a very early stage). Consequently, respondents proposed equally (f=0.56, df=37, and p>.05) that urgent actions (within 0-5 years) were needed for integrating construction with process through such avenues as BIM, integrated product and process delivery (IPPD) etc.

4. Theoretical Proposition and Development of a New OSM Agenda

4.1 *Introduction*

Given the above context and findings presented in this chapter, it was considered important to use these outcomes as a starting platform for further investigation. The rationale behind this theoretical proposition was to i) enhance data fidelity, ii) improve validity, reliability and generalisability, and iii) to update the original findings to improve currency (given that five years had elapsed from the original research, and three years from the follow-up research). That being said, it was also important to understand and engage robust methodological approaches that took into account both ontological and epistemological viewpoints (Love *et al.*, 2002). One concern was following similar patterns (and approaches) might not necessarily be appropriate, given that researchers' experiential knowledge can often influence their "worldview" (Holt and Goulding, 2014).

4.2 *Research Approach*

Research findings from CIB TG74 indicated that new OSM production and business models were needed for future industry uptake (Goulding and Arif, 2013; Goulding *et al.*, 2015). Similar findings have also been espoused in extant literature (Theusen and Lars, 2013; KPMG, 2016; House of Lords, 2018). Therefore, the first stage in this process was to use purposive sampling to select a new 'representative' population sample to re-visit these findings. In doing so, 15 new OSM 'experts' were included in this research. These respondents represented the following countries: Australia, China, Denmark, Egypt, Finland, Germany, India, Malaysia, Norway, Russia, Sweden, Turkey, UAE, UK and US. In order to secure consistency, the research approach adopted replicated that identified in Section 3. A Focus-Group-Discussion methodology (Morgan, 1997), was considered useful for generating ideas regarding new products and phenomena based on experts' commonality (Parker and Tritter, 2006; Creswell, 2018).

Respondents were asked to rank the following categories:

A. Process Improvement
B. Innovation (competitive advantage)
C. Technology (BIM, new tools, big data etc.)
D. Visualisation and Integration (through current/emerging digital technologies)
E. Production and Process Models
F. Strategic and Operational Business Models
G. Training and Development
H. Sustainability (as key a USP)
I. Value (through life – customisation, change in use etc.)
J. Materials (skins, retrofitting, smart components etc.)

The ranking process was based on a simple 1-10 scale, where 1 = highest level of importance, and 10 = lowest level of importance. Only one number assignment could be used for each of the ten categories. For example, if a respondent felt that the most important issue was 'A', then this was allocated "1", and the next most important issue was 'F', then this was allocated a score of "2" until all ten areas had been prioritised. The adoption of this approach enabled the compiled data set to represent all views, where the lowest combined score indicated the highest priority (from all respondents). This approach ensured that a decision had to be made by each respondent, thereby avoiding split decisions. These results were then discussed through the Focus-Group-Discussion methodology. However, this specifically excluded capturing the corresponding rationale of each respondent's views, nor did it attempt to analyse individual decisions.

4.3 *Research Findings*

Research findings from this study are presented in Table 2. This depicts 15 individual scores covering a range of 1-10, where a score of 1 was classed as the highest level of importance over ten categories (A-J). These scores are 'raw' and unadulterated. They can not be unilaterally or collectively considered 'representative', nor do they reflect any geographic viewpoint, job role or sector (design/manufacturing/construction). These are purely results based on respondents' perceived level of importance over the ten unit of analysis areas.

Table 2: Level of Importance Results (A-J)

Category Ranking (where 1 = high)	Respondents 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total	Rank	Importance
A. Process Improvement	1	3	1	9	2	4	1	4	4	4	4	9	5	4	5	**60**	**8**	**3**
B. Innovation (competitive advantage)	5	1	10	6	1	6	4	6	5	6	3	1	1	2	2	**59**	**9**	**2**
C. Technology (BIM, new tools, big data etc.)	2	2	2	5	9	5	3	5	6	5	5	4	4	5	6	**68**	**5**	**6**
D. Visualisation and Integration (through current/emerging digital technologies)	3	7	3	10	10	10	5	9	10	10	8	7	6	7	8	**113**	**3**	**8**
E. Production and Process Models	8	5	5	8	3	3	8	2	3	3	2	3	2	3	3	**61**	**7**	**4**
F. Strategic and Operational Business Models	9	4	6	7	4	2	6	1	1	2	1	2	3	1	1	**50**	**10**	**1**
G. Training and Development	4	6	4	1	5	1	7	3	2	1	6	6	7	6	4	**63**	**6**	**5**
H. Sustainability (as key a USP)	10	10	7	2	6	8	9	8	8	8	9	8	10	8	7	**118**	**2**	**9**
I. Value (through life – customisation, change in use etc.)	6	9	8	3	8	7	2	7	7	7	10	10	8	9	10	**111**	**4**	**7**
J. Materials (skins, retrofitting, smart components etc.)	7	8	9	4	7	9	10	10	9	9	7	5	9	10	9	**122**	**1**	**10**
checksum	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55			

The findings presented in Table 2 present a stratified distribution of opinions. Given the limited sample set, nominal coding and range; so statistically, these findings could on face value be considered somewhat anomalous. However, they start to add value and meaning when supported by qualitative data (from the transcripts). The key salient points from these discussions are presented through the following four points:

- **Strategic and Operational Business Models [Category F]** were considered the most important issue to address over the short-medium term. It was acknowledged that companies and investors were somewhat cautious (and perhaps reticent) to fully commit to OSM without knowing more. High level strategic decisions of this nature needed evidence to support investment;
- **Innovation (competitive advantage) [Category B]** provided insight into the importance of embedding OSM innovation into products and service provision. This was seen as a clear demarcation indicator, and one which could be used to secure strategic advantage. The inhibitor to this was seen as lack of research and development, or lack of understanding of how to truly leverage the 'innovation premium';
- **Process Improvement [Category A]** was seen as one of the main tasks that needed to be fully understood. Traditionalist thinking made people feel cautious and somewhat protective of the "old ways of doing things". In some respects, respondents felt that they did not know enough about the manufacturing side of process delivery, let alone DfMA, IPPD, concurrent engineering, enterprise resource planning or advanced lean methodologies;
- **Materials (skins, retrofitting, smart components etc.) [Category J]** was considered the least area of importance. This was probably due to two factors. First, respondents found it difficult to understand what this actually meant, and how this related to OSM (and the wider OSM agenda). Second, respondents that did

understood this category very well [R4 & R12] highlighted that the retrofitting market was a niche area, but was growing. However, businesses needed to understand the fundamentals of OSM first before branching into things like retrofitting, smart skins/components etc.

4.4 *The Need for Radical Change*

The findings presented in this chapter so far have highlighted a number of factors that still need to be addressed. In fact, it is proffered that a paradigm shift in OSM thinking is needed, so that the offsite community (design, manufacturing and construction) and societal stakeholders (governments, regulators, financiers, clients, customers, legislators etc.) can openly promote and defend offsite. AEC has a lot to be proud of (as elucidated earlier). However, it is equally acknowledged that these issues are complex and multi-layered. Geographical context aside for one moment, the offsite community is as strong and as buoyant as it has ever been. The challenge therefore is to systematically embrace these challenges one by one in order to develop sector resilience. This will require stakeholders to actively embrace change, which will undoubtedly be uncomfortable for some. It will also require new thinking and new approaches to business. This will inevitably cause organisational disruption; but equally, may also provide new opportunities to innovate and create more sustainable business models. New business models are therefore needed. These will need to be agile, flexible and responsive. The market is changing, technology is also changing – so must processes and the ways through which businesses interact and compete. Moreover, business models and strategy need to be purposefully aligned to market forces (Ansoff, 1970; Porter, 1979; Andrews, 1987).

From a market forces perspective, OSM embraces a number of complex systems and stakeholder dependency chains. These are inextricably interlinked. Some of these links and relationships extend to the manufacturing sector (to a varying or lesser degree). However, the shape and directional pattern of these relationships are still unfolding. In many respects, this uncertainty has reinforced entrenched positions, the corollary of which has surreptitiously stifled OSM development and subsequent landscape. These relationships, forces and drivers are significant and palpable. Therefore, the antecedents of AEC and OSM need to change. This need for change was highlighted through four strategic challenges: "Productivity", "Certainty in delivery", "Skills shortage" and "Data transparency" (KPMG, 2016). Finally, it is also important to identify the causal stimulants and impediments to success in order to 'predict' organisational transitional arrangements (from a strategic prism perspective). This will mean taking a cold hard look at all business operations. Challenges can be turned into opportunities. This will invariably require reflective repositioning of strategic goals, and perhaps seed investment in new areas. Organisational learning (Senge, 1990; Huber, 1991; Vakola and Rezgui, 2000) will also be a key part of these transition arrangements.

4.5 *OSM Resilience: Envisioning the Future Agenda*

Given the need to change, a number of advanced decision support tools are available to help OSM stakeholders. These include process-driven BIM and similar advanced stochastic simulation models, all of which offer unique insight into business case options (using probability generation for predicting outcomes using "what-if" scenarios). In addition, discrete event simulation packages now provide high-level visibility into each scenario generated, which when coupled with DfMA principles can help confirm product surety through a raft of evidential metrics. Moreover, it is also time to reflect on why AEC has remained somewhat intransigent when compared with other sectors such as pharmaceuticals, aerospace or information technology service provision (Forbes, 2018). That being said, change is on the horizon, with evidence suggesting that disruptive technologies such as 3D printing, cellular fabrication and blockchain are increasingly enabling AEC businesses (Proffitt, 2017; March, 2017; McKinsey, 2017; Raconteur, 2018). Additional areas for OSM exploitation also include the integration of servitisation into business models. Where 'servitisation' is the provision of additional (layered) services offered to the client over an assets lifespan (or agreed time period). Several progressive companies are now providing options such as this into their service provision portfolios in order to not only create organisational resilience, but secure long-term revenue streams through diversification models and strategies.

Reflecting back on the historical developments of OSM, especially over the last 20 years or so, perhaps it is time to start thinking about the future. Literature, reports, working groups, research bodies, trade organisations, academia, governments, professional bodies and bespoke OSM communities all have different views. Moreover, the empirical work presented in this chapter supports this diversity. The challenge is "can we really see the bigger picture ….or even "can we envision the future"?. The safest answer to these questions would be to say "no", or at least "probably not". However, in order to provide some structure and semblance, a simple OSM model for envisioning the future is presented for discussion (Figure 3).

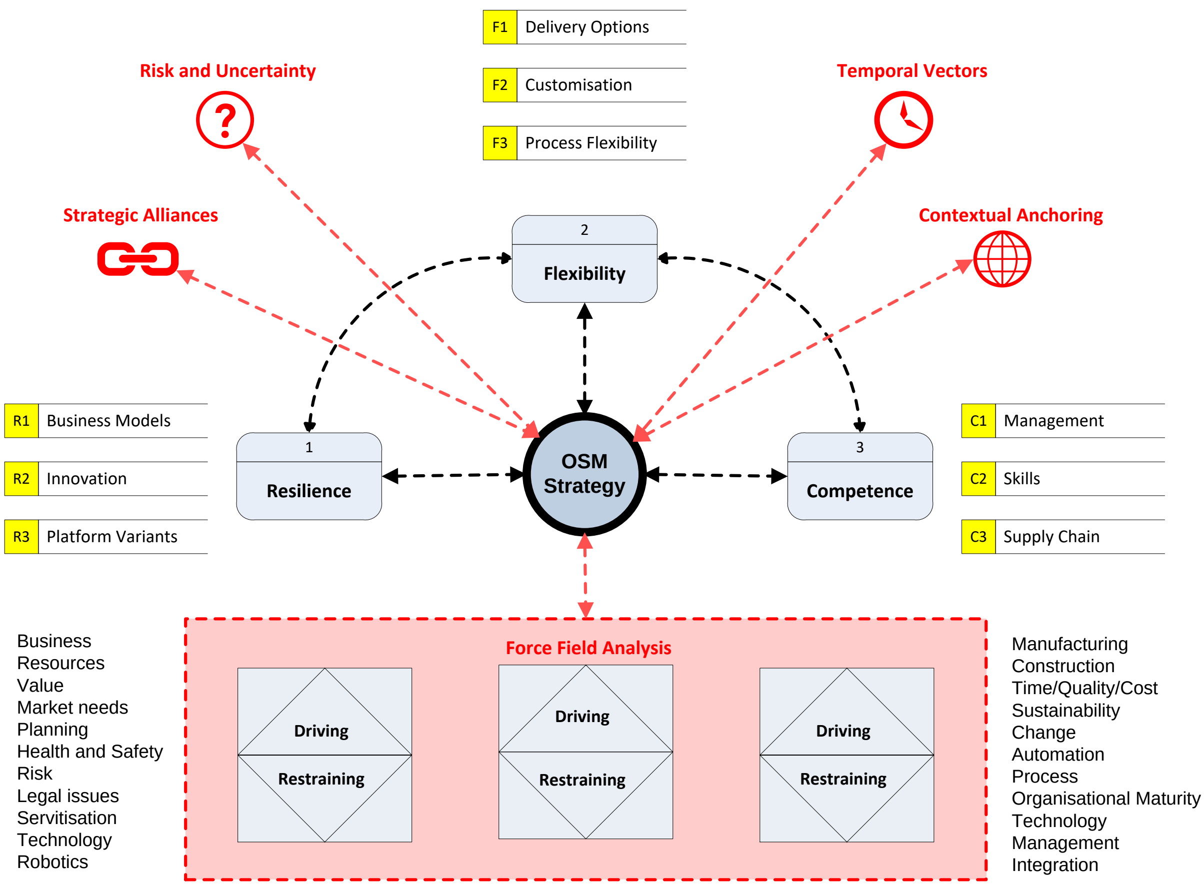

Figure 3: OSM: Envisioning the Future Agenda

Figure 3 presents a number of interconnected issues that need to be considered in order to deliver viable OSM ‘market ready’ solutions. The central core “OSM Strategy” acts as the linchpin or fulcrum through which all activities are actioned. It is important that all antecedents that feed into this central core have clear evidence indicators to support decisions. Moreover, data veracity is essential. From this central core, three process boxes are presented: 1: “Resilience”, 2: “Flexibility” and 3: “Competence”. These three processes contain the ‘ingredients’ required to deliver the OSM Strategy. For example, process box 1 “Resilience”, contains three main fields: R1, R2 and R3, representing “Business Models”, “Innovation” and “Platform Variants” respectively. Each one of these fields will need to be populated with data needed to support successful OSM solutions. The weighting applied to each of these three areas to process box 1 are neutral (or equally weighted), in order to remove or minimise bias or skew. That being said, some organisations may wish to apply weightings cognisant of *a priori* knowledge. The information provided in these three fields (R1, R2, R3) is customisable to the organisation (and level of maturity with OSM). Some may wish to follow internal or bespoke analytical approaches to each of these fields, whilst others may wish to use other approaches such as performance frameworks, key performance indicators, Management by Objectives, Balanced Scorecard, intelligent dashboards etc. Once this information has been captured, the same process is undertaken for process box 2: “Flexibility” and process box 3: “Competence”. The upper semicircle of Figure 3 contains four outliers (detached from the main ‘system’ OSM), representing “Strategic Alliances”, “Risk and Uncertainty”, “Temporal Vectors” and “Contextual Anchoring”. These four areas are considered external independent variables. These are considered particularly important, as any changes made to these are usually beyond the locus of control of the company (as they are external factors). For example, insolvency of a strategic partner in an alliance, a change in interest rates, societal ‘leaning’, new legislation etc. These factors therefore need to be included as part of the analysis.

The lower semicircle of Figure 3 depicts a Force Field Analysis section. Three boxes are included in this section as an exemplar. However, the actual number will depend upon the organisational structure, number of business units and devolved reporting activities. These three boxes capture the present state (sometimes referred to as the desired state), the driving forces (needed for change), and the restraining forces (barriers restricting/preventing change from happening). The rationale behind this is based on equilibrium change, where the greatest force changes the equilibrium one way or the other (Lewin, 1951). Given this, a number of indicators are presented for analysis, ranging from market drivers, sustainability and process, through to automation and servitisation. For example, should ‘sustainability’ be chosen, then the Force Field Analysis would need to identify all the driving forces and corresponding barriers. These would typically include everything from OSM’s ability to deliver ‘green credentials’, through to reduced waste, lower carbon footprint, smarter materials/skins, reduction in transportation, lower embodied energy, lower lifecycle costs, increased adaptability etc. This would need to be supported by evidence, including literature, reports, case studies, testimonials, provision of extended warranty schemes, satisfaction surveys etc. Items may be added or deleted from the Force Field Analysis section according to need. The results from the collective Force Field Analysis section are then processed through the central core “OSM Strategy” for final analysis and reflection. The OSM strategy is then hard coded for subsequent execution.

5. Conclusion

This chapter presented a personal reflection on OSM, from its origins, through to embryonic growth, and a small amount of 'crystal ball gazing'. Literature was discussed, emphasising the need to create transparent evidential chains to deliver viable business propositions. Innovation and change were highlighted as forward trajectory points, noting that the OSM market provides several fertile opportunities. Initial findings from CIB Task Group TG74 (New Production and Business Models in Construction) were then presented and discussed in order to partly explain international context; but more importantly, to highlight that much more needed to be done. Additional evidence included the identification of nine core areas and their impact on AEC. This was supplemented by an additional study which emphasised the need to i) create new strategic and operational business models, ii) embed innovation (as an innovation premium driver) in all aspects of the business, and iii) develop process improvement initiatives cognisant of such factors as DfMA. The culmination of this chapter presented a simple model which envisioning the future of OSM. This highlighted the need to develop defendable 'market ready OSM solutions, through three core processes (Resilience, Flexibility, Competence) and a Force Field Analysis section. This model will need further testing (post-population) to meet internal/external validation criteria, including consistency measures and reliability tests.

Key Learning Points

- ✪ The OSM market has not yet reached maturity, it continues to grow (almost exponentially). However, AEC uptake is still very low, with only a few companies (start-ups and mature), willing to invest. Those that have, are starting to generate business success, particularly though niche market exploitation and innovation premium roll-out;

- ✪ The adoption of OSM is not for the faint hearted. It requires considerable thought, research and investment. Conventional siloed (entrenched) thinking will need to be left behind, requiring radical thinking and new ways of doing things to meet DfMA, IPPD etc. This will involve investment, change, new skills, new production and assembly philosophies etc;

- ✪ There is an explicit need to develop evidenced-based OSM business models. These are needed to help provide the intelligence needed for improving market confidence and delivering future OSM uptake. Resilience is also an important factor here, requiring the collective action of the whole supply chain, including: research bodies, trade organisations, academia, governments, professional bodies and bespoke OSM communities to all "sing from the same hymn sheet".

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